



## Technology Readiness Assessment for HEEET TPS

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IPPW July 11, 2019

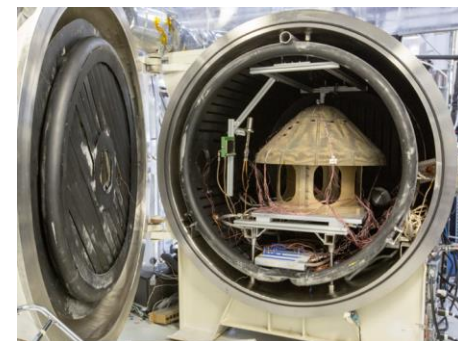
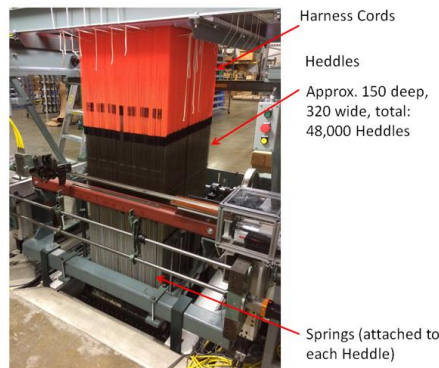
TECHNOLOGY DRIVES EXPLORATION



# Heatshield for Extreme Entry Environment Technology (HEEET)



- Leverages advanced 3-D weaving and resin infusion.
- A dual layer system - robust and mass efficient across a range of extreme entry environments
- Objective to:
  - Mature HEEET to TRL 6
  - Develop and verify:
    - Manufacturing processes
    - Design tools:
      - ❖ Thermostructural
      - ❖ Aerothermal Response
    - Documentation



Thurs 11:54 am The Challenges of Seam Design in Tiled Thermal Protection Systems. Cole Kazemba

Thurs 1:34pm. Damage Assessment During a Structural and Thermal Test Campaign of a 1-meter Diameter Heatshield with a 3-D Woven Thermal Protection System for Extreme Environments. Sarah Langston

Fri. 10:54am Challenges In Qualification Of Thermal Protection Systems In Extreme Entry Environments. Milad Mahzari

Fri 1:57pm White Papers For The Next Decadal Survey: Thermal Protection Systems And Instrumentation. Helen Hwang.

Poster Session 1: A25 IV.1 High Velocity Impact Performance of a Dual Layer Thermal Protection System for the Mars Sample Return Earth Entry Vehicle. Ben Libben

Poster Session 2: B25. VII.4. Maturation of Heatshield for Extreme Entry Environment Technology (HEEET) through Extreme Aero-thermal Ground Testing at Arnold Engineering Development Complex (AEDC). Joseph Williams

## Mission Applications:

Tues 2:48pm. Robotic Mars Sample Return Earth Entry Vehicle Concept Development. Marcus Lobbia

Tues 3:00pm. HEEET Material Modeling and Earth Entry Vehicle Landing Analyses for Potential Mars Sample Return. Aaron Siddens



# TRL Assessment

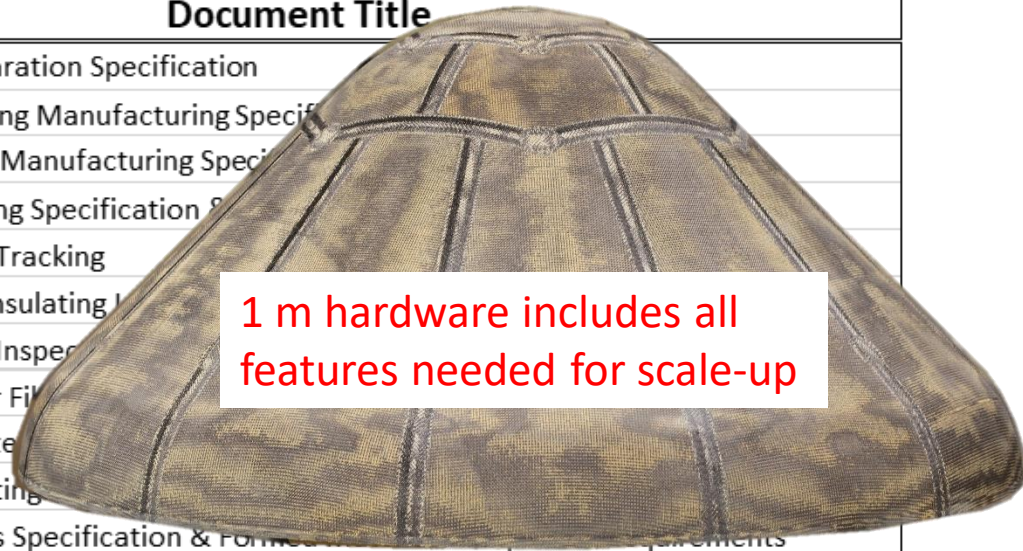


- **Goal: Decide whether HEEET technology is at TRL 6**
  - Technology elements
    - Acreage material
    - Seams including gap-filler in channel between acreage tiles with Nitrile Phenolic film adhesive around gap-filler
- **Definition for TRL 6 (NASA Systems Engineering Handbook)**
  - *A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.*
- **Exit (or success) criteria are:**
  - *Documented test performance demonstrating agreement with analytical predictions.*
- **Have we built high-fidelity prototypes that address scaling issues?**
- **Have we operated in relevant environments? Difficult for TPS for extreme environments**
  - Structural (pressure, thermal-vacuum and point loads on 1 m ETU)
  - Thermostructural (combined loading of flexures)
  - Aerothermal (arc-jets)
- **Have we documented test performance demonstrating agreement with analytic predictions?**

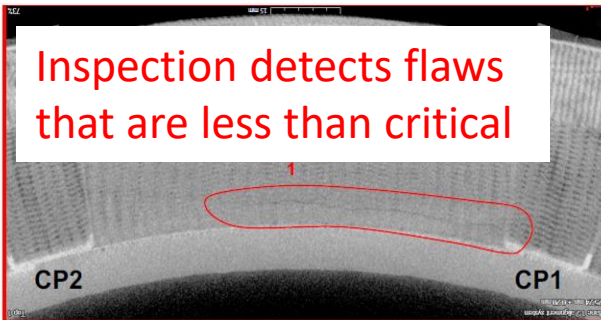


# Prototype Hardware

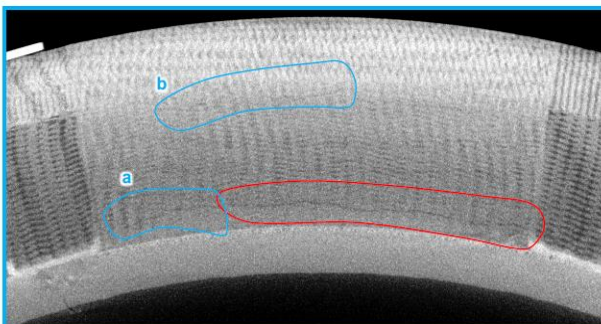
Document Number	Document Title
HEET-4001	Infusion Solution Preparation Specification
HEET-4002	Resin Infusion and Curing Manufacturing Specification
HEET-4003	Drying and Post Curing Manufacturing Specification
HEET-4011	HEET Material Handling Specification
HEET-4013	HEET Part Marking & Tracking
HEET-4014	HEET Blended Yarn (Insulating Layer)
HEET-4015	HEET Fiber Receiving Inspection
HEET-4016	HEET Recession Layer Filament
HEET-4018	HEET Dry-Woven Material
	Woven Cutting
	ing Process Specification & Forming
	Receiving Inspection for Recession Layer AS4 Tows
	d Material Inspection and Acceptance Requirements
	anufacturing Process Specification
	spection & Acceptance Requirements
	ial Machining Process Specification & Acceptance Requirements
	egration Process Specification
	spection and Acceptance
	ufacturing Requirements
	urface Densification
	ut Plug Manuf. and Integration Process Specification



1 m hardware includes all features needed for scale-up



Inspection detects flaws that are less than critical



Comprehensive procedures support consistent reproducibility

Small test articles use consistent procedures

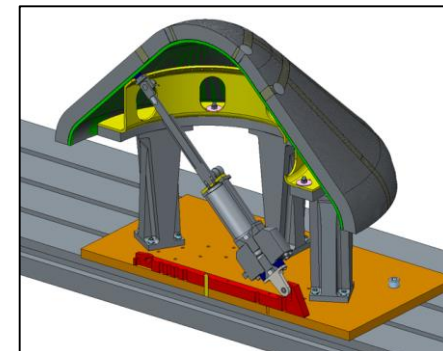
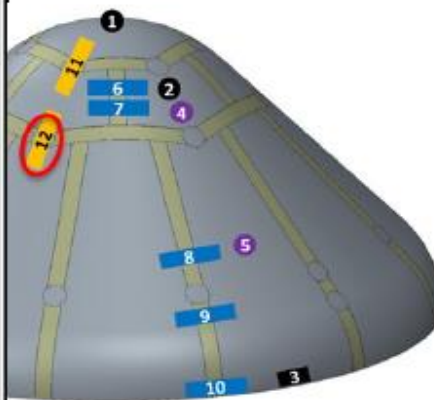
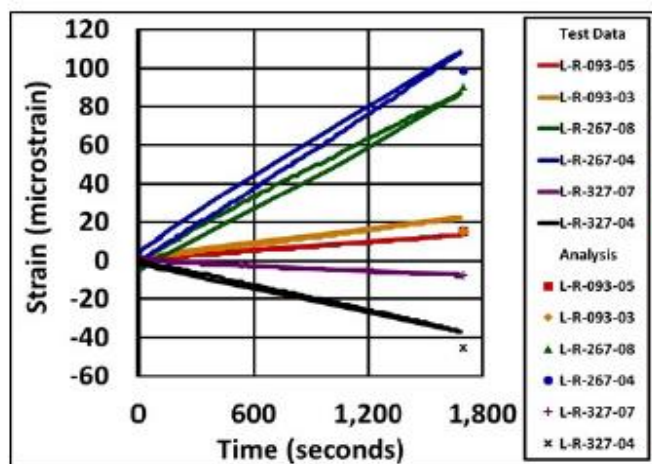


# Structural Capability

## Load Cases other than Entry



- Sample result for point load case



Component	Mode	Property	Basis for Allowable	Margin Approach	Margin / Factor	Confidence
Tile Failure	TTT cracks	IP tensile strength	Material Testing	Structural	> 5	High
		IP shear strength	Material Testing	Structural	> 3	High
	IP cracks	TTT tensile strength	Material Testing	Structural	> 5	High
		Interlayer Shear Strength	Material Testing	Structural	> 1	High
Base bond	Adhesive mech. failure	Joint tensile strength	Joint Testing	Structural	> 5	High
		Joint shear strength	Joint Testing	Structural	> 5	High
Seam bond	Mech failure	Joint tensile strength	Joint Testing	Structural	> 5	High
		Joint shear strength	Manufacturer Database	Structural	> 5	High
		Triple point strain	Joint Testing	Structural	> 1	High

### Weakest correlation in regions of high curvature

- Material properties affected by forming
- Uncertainty is acceptable

### Margins much larger than model uncertainty

### Evaluation

- Delivered test results that correlate with model

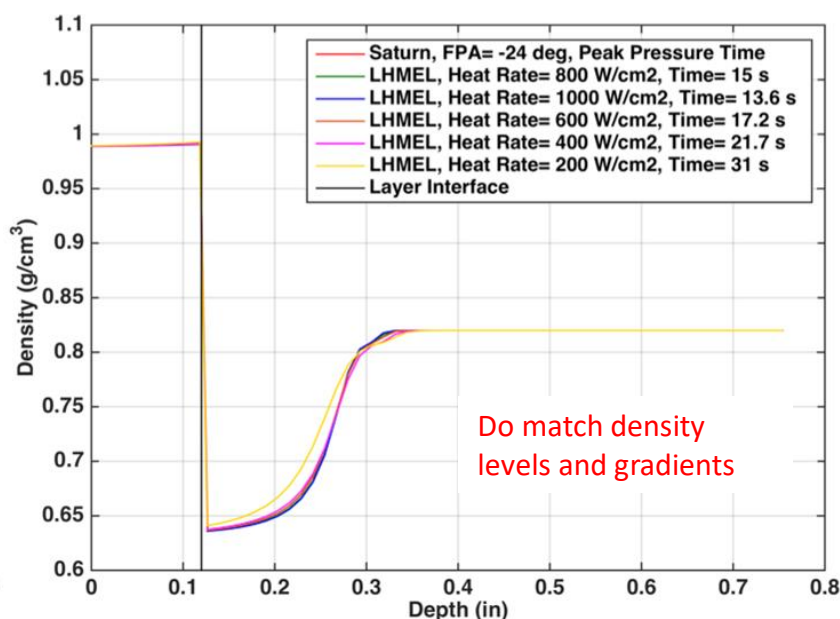
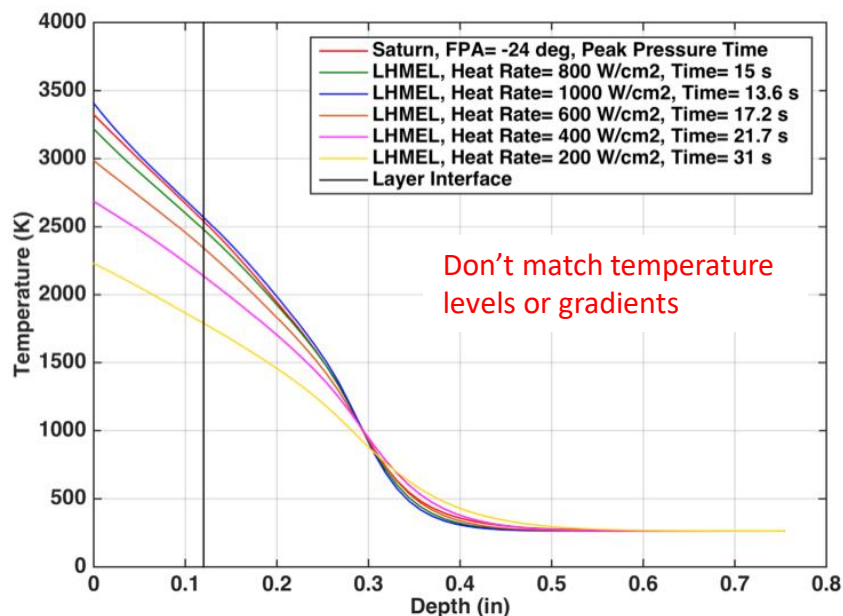
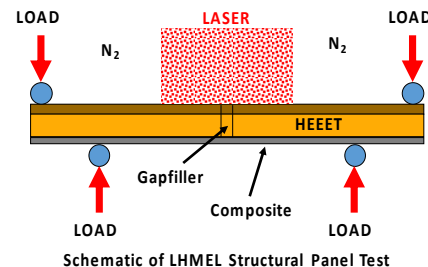


# Thermostructural Environments for Entry



- **Mission-accurate heating rates on seam article are challenging in ground facility**

- Can deliver relevant material state by heating for longer at lower rates
- Can apply bending load throughout heating (as material changes state)
- Can vary bending load after material state changes are in progress



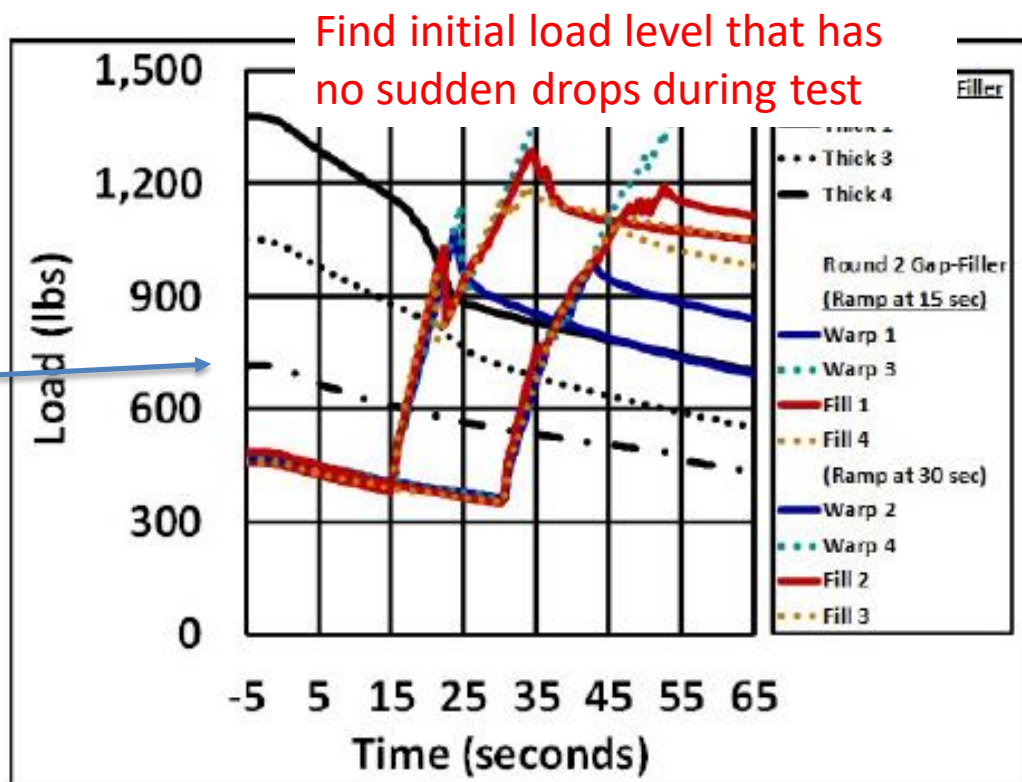
- **Evaluation**

- Achieved relevant environments for thermostructural load throughout entry

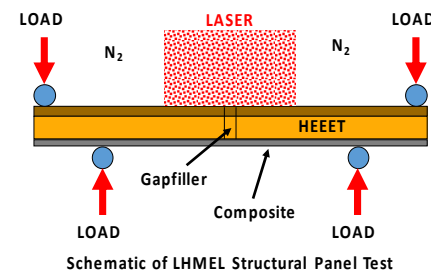


# Thermostructural Capability at Entry

- **Challenging to develop predictive model for local stresses at seam**
  - Uncertainty in material properties
  - Stress concentration at interface between char and virgin adhesive
- **Rely on estimation of gapfiller expansion at RT pre-loading**



FEM predicts 0.02" gapfiller expansion at this load



Panels with closeout plugs had no failure below 0.009" expansion (not shown)

Need up to 0.003" expansion.

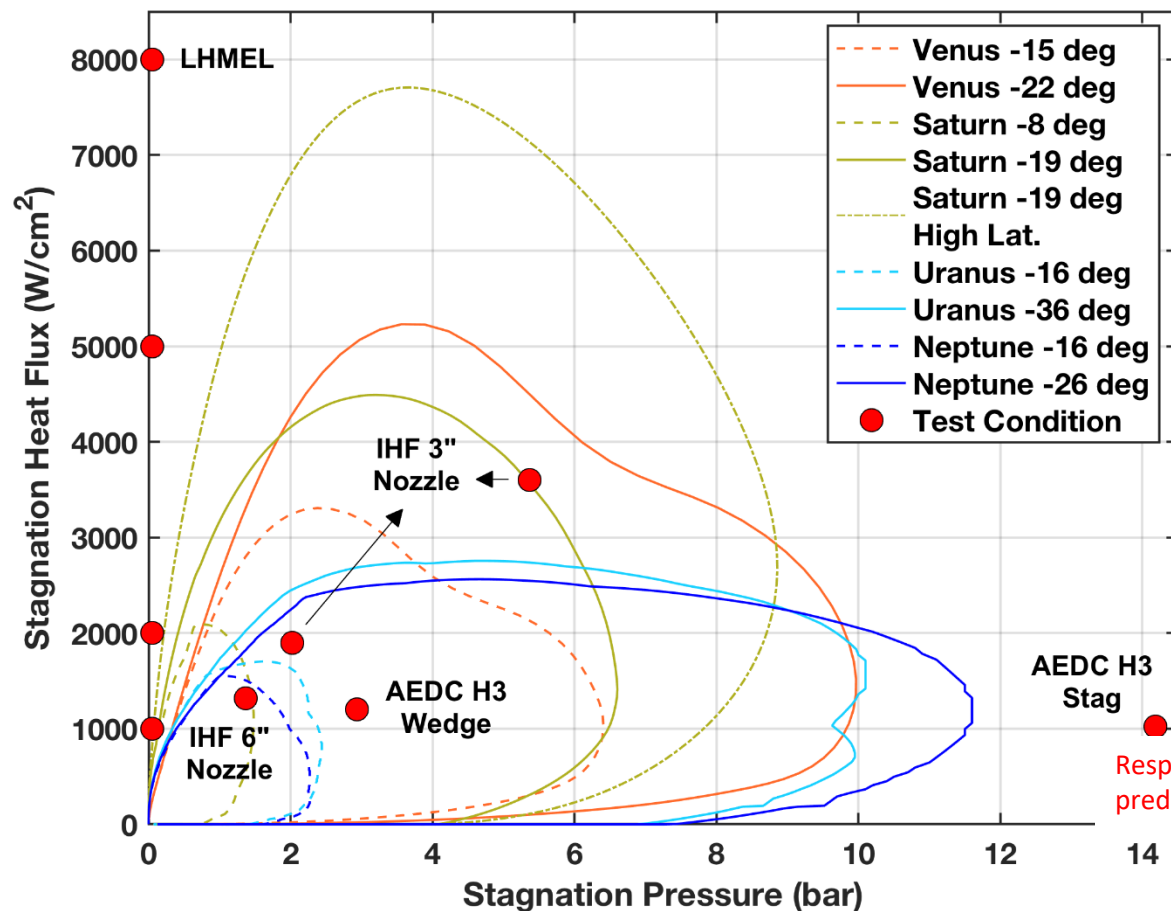
Large margins



# Aerothermal Environments



- **Challenging to achieve extreme environments in ground facilities (Mahzari, Friday at 10:54)**
  - Introduced testing of 1" models in 3" nozzle at IHF
  - All parameters are not matched simultaneously
  - Need to account for cold wall vs hot wall
  - Limitations would apply to ANY material intended for extreme environment applications



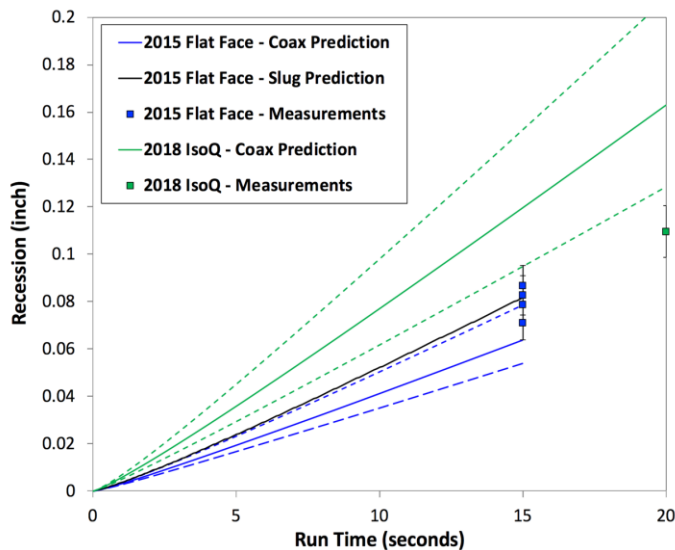
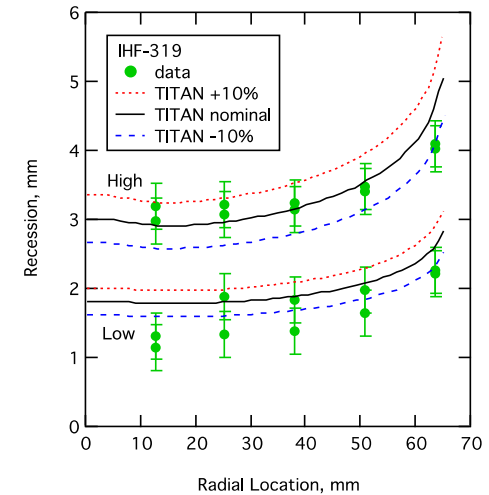
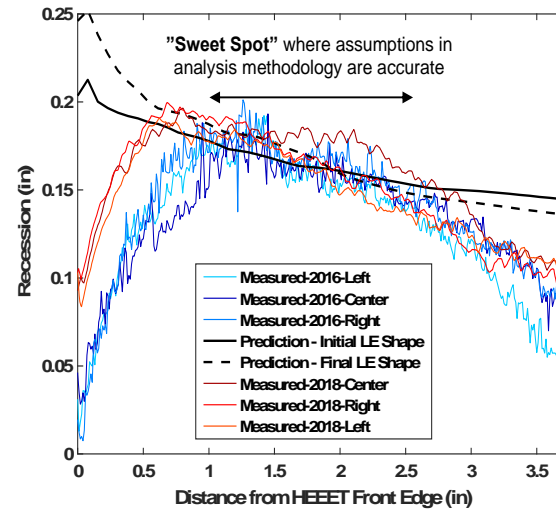
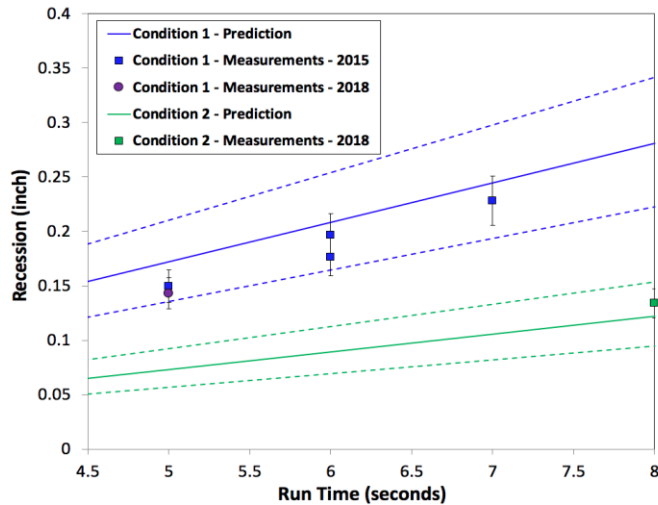
Evaluation: achieved adequate aerothermal environments

NOT High latitude Saturn  
NOT steep Venus

Response model not predictive at this condition



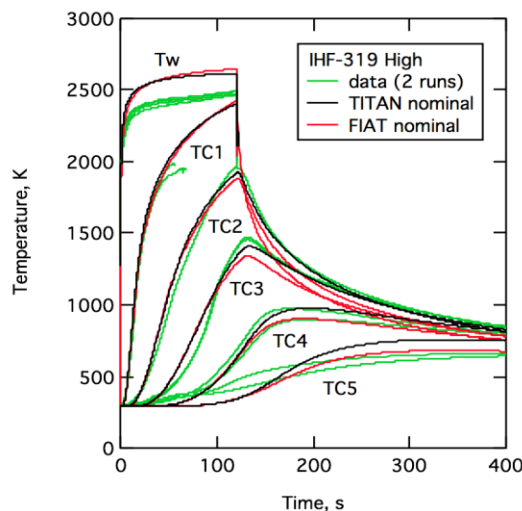
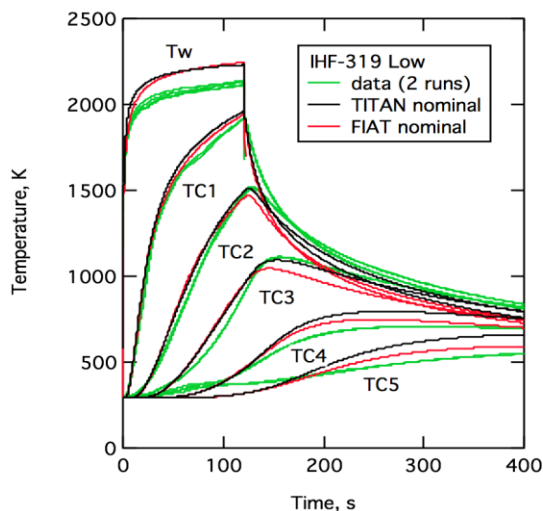
# Recession Prediction



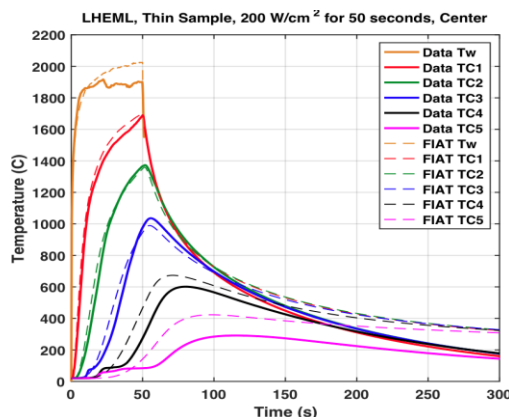
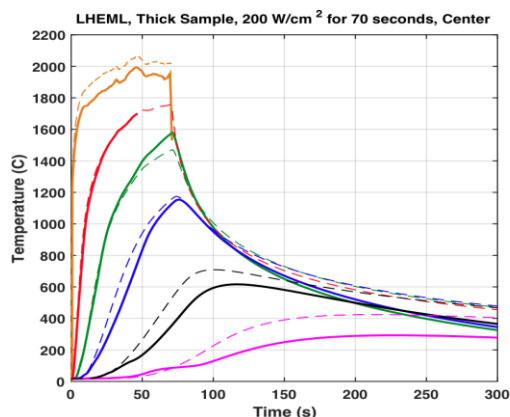
- **Excellent results for most tests**
  - Concern for 2" models in 6" nozzle
    - Over-predicts for iso-Q in 2018
    - Under-predicts for flat face in 2015
    - Uncertainty is bounded by recession margin (50% recommended)
- **Evaluation**
  - Test results have adequate agreement with recession model



# In-depth Temperature Prediction



Stagnation testing in  
IHF 13" nozzle



Laser testing at LHMEEL

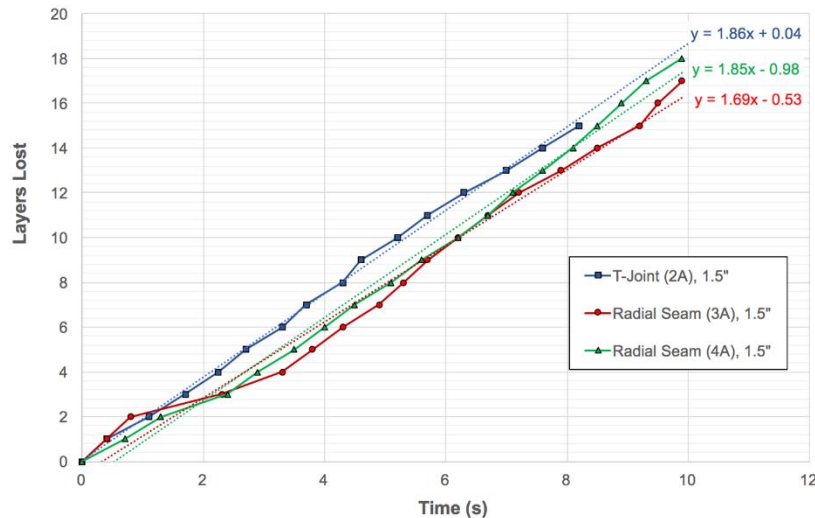
Limited measurements  
under seams show no  
elevated temperatures  
relative to acreage

## • Evaluation

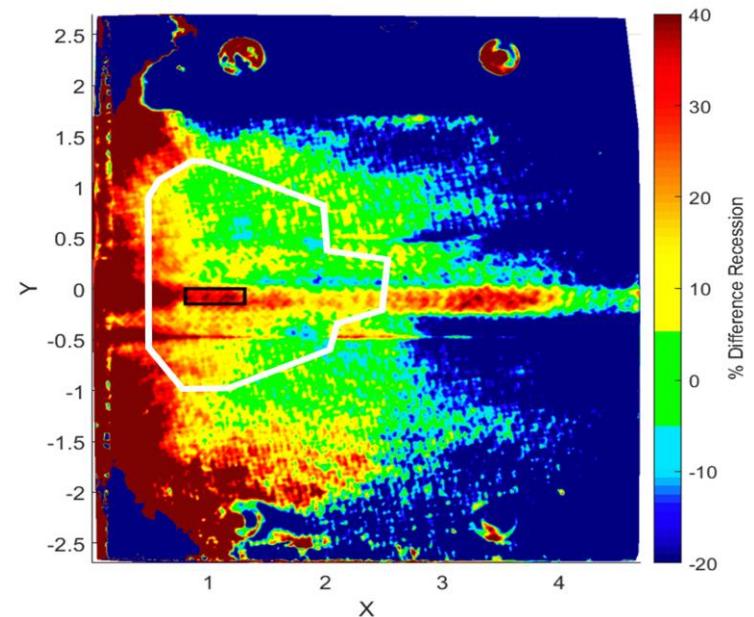
- Test results have adequate agreement with model predictions of temperature



# Recession of Seams



No run-away observed



Difficult to assess augmentation due to uncertainty in applied environment

- **Measured recession augmentation in 2018 test ranged from 11 to 51%**
  - Most measurements in 20-40% range
  - Probably exacerbated by thin leading edge
- **Evaluation – adequate recession predictability, can be handled with margin**



# Final TRL Assessment



- **Have we built high-fidelity prototypes that address scaling issues?** Yes
- **Have we operated in relevant environments?**
  - Aerothermal (arc-jets) Yes
  - Thermostructural (combined loading of flexures at LHMEEL) Yes
  - Structural (pressure, thermal-vacuum and point loads on 1 m ETU) Yes
- **Have we documented test performance demonstrating agreement with analytic predictions?** Yes
- **HEEET system is assessed to be at TRL 6**
- **Limitations**
  - Not at TRL 6 for thickness much greater than 2"
  - Not at TRL 6 for applied environments above 5 atm and 3600 W/cm<sup>2</sup>
  - No mission opportunity (except Jupiter) appears to require these levels
- **But don't just take our word for it**
  - "The IRB concurs [...] that the overall objective of achieving TRL 6 has been completed"